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[54] **DIGITAL DEMODULATOR AND METHOD OF OPERATION**

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[52] **U.S. Cl.** **375/341**; 714/795; 375/262
[58] **Field of Search** 371/43.1, 43.6,
371/43.7, 43.8; 375/262, 326, 341, 354,
359; 364/728.01; 714/786, 794, 795, 796

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[57] **ABSTRACT**

A demodulator performs both synchronization and decoding concurrently by decoding a received preambleless signal according to Viterbi-decoding scheme and determining a time alignment function n(t) which indicates where the decoded sequence is located in a time period of the received signal. After converting the received preambleless signal to a received sequence in a sampling rate which is at least the predetermined symbol rate, a Viterbi decoder is synchronized with the received sequence while determining the time alignment function n(t) so that the Viterbi-decoded sequence is closest to the received sequence.
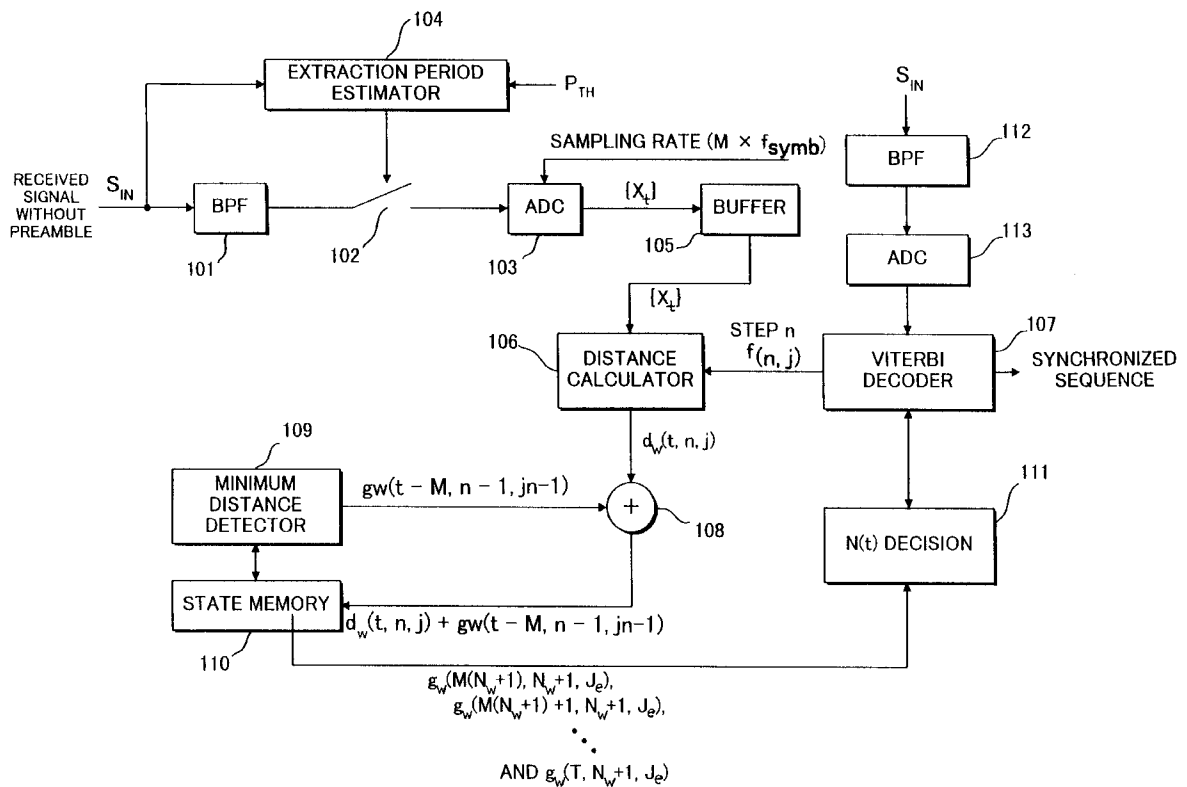
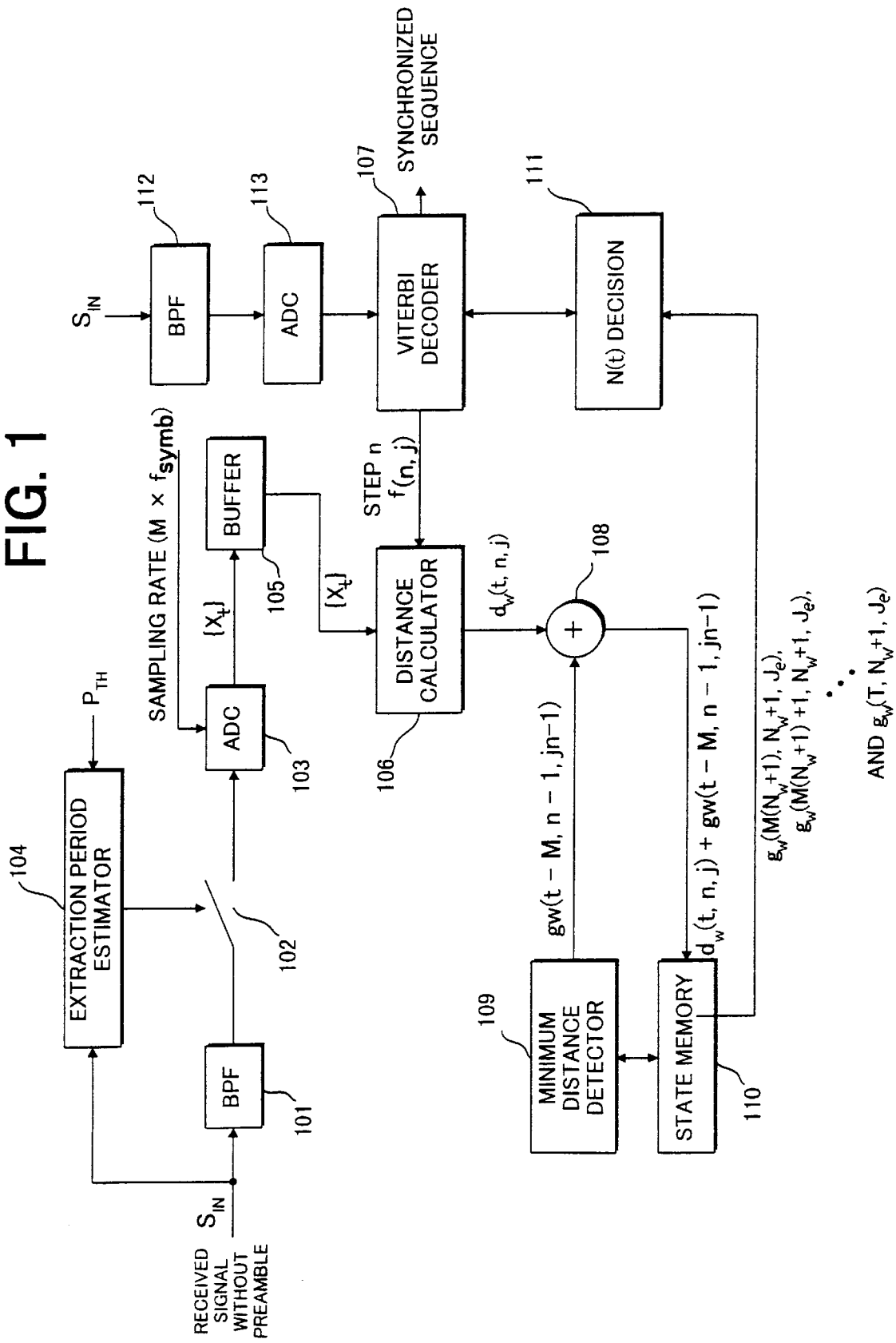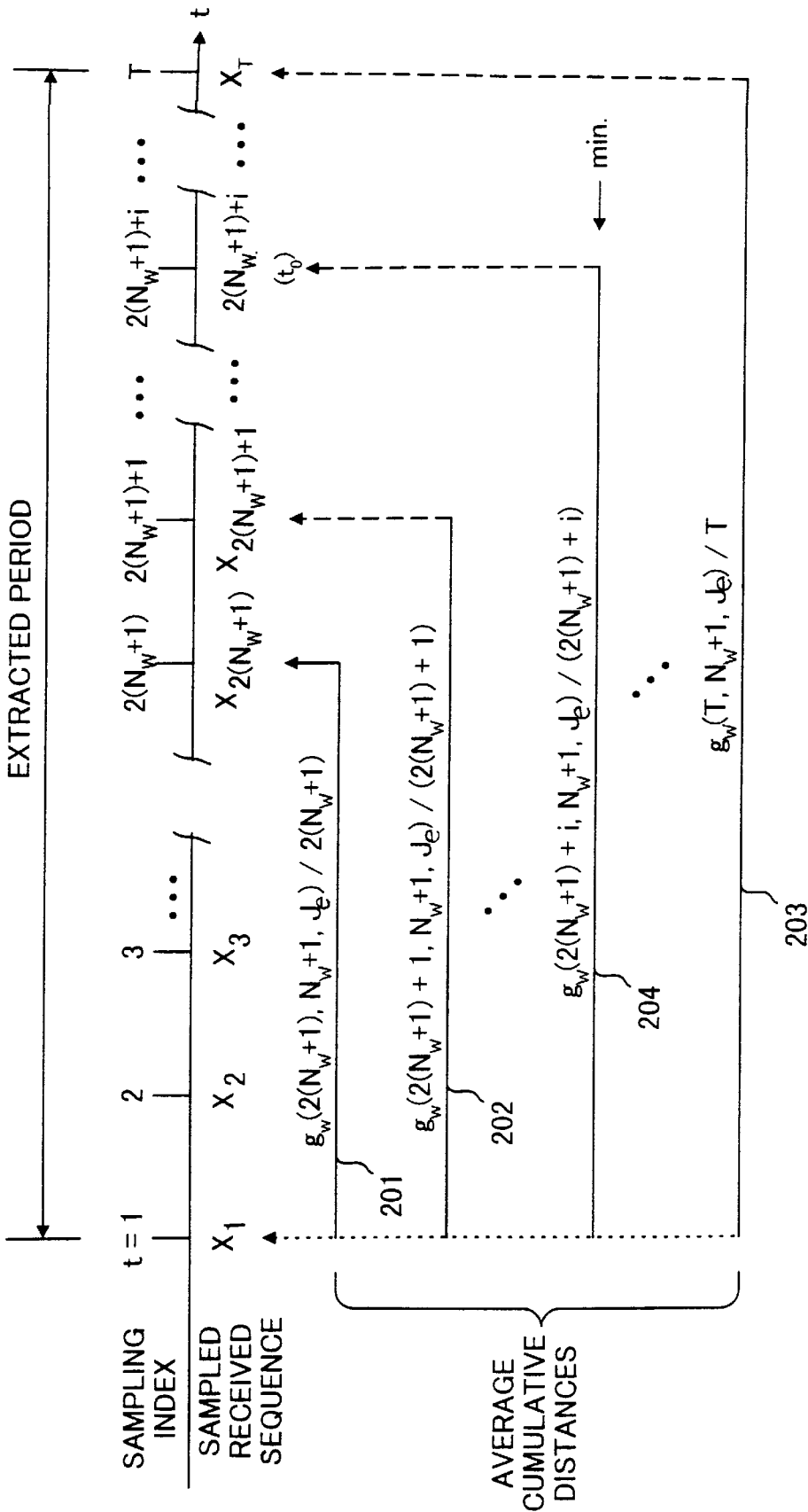**15 Claims, 3 Drawing Sheets**

FIG. 1

FIG. 2

FIG. 3

$$\frac{(t - t_0) / 2 + N_W + 1}{}$$
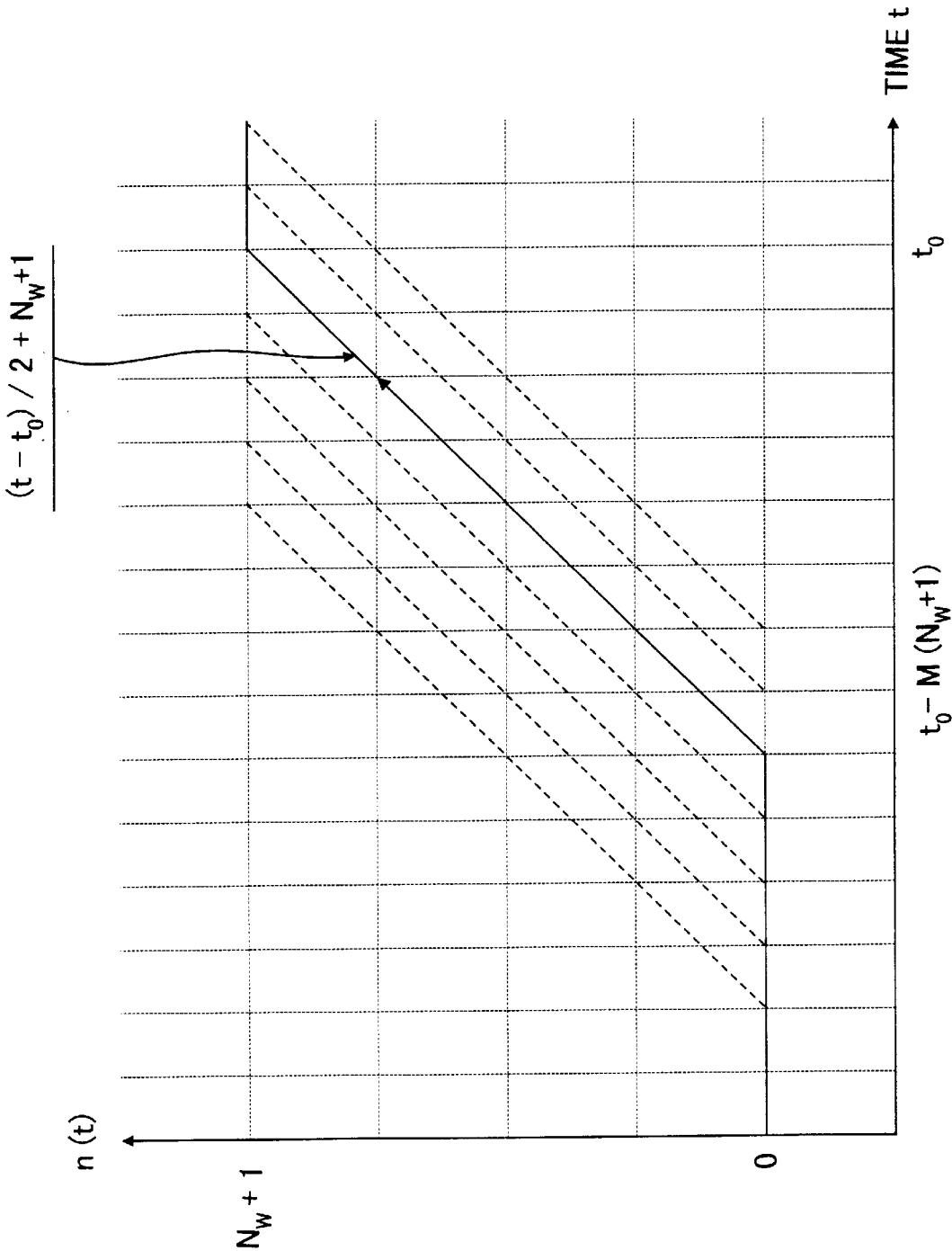
$n(t)$

$N_W + 1$

0

TIME t

t_0

$t_0 - M (N_W + 1)$

1

DIGITAL DEMODULATOR AND METHOD OF OPERATION

BACKGROUND OF THE INVENTION

1. Field of the invention

The present invention generally relates to a digital demodulation technique in a wireless communication system.

2. Description of the Related Art

In a digital demodulator, coherent detection or differential detection is performed before bit synchronization and then symbol decision is performed using a detected baseband signal at bit-synchronized sampling points. However, according to such a demodulation method, the carrier recovery and symbol synchronization performance have a great effect on the receiving characteristic.

It is also known that the demodulation performance is improved by receiving a predetermined training signal or a preamble signal. More specifically, the predetermined training signal is used to calculate a decision error. The decision error is fed back to an equalizer and a phase-locked loop to compensate for distortions including linear distortion and group delay distortion.

In the case of mobile communications, however, since radio channel characteristics frequently vary, it is necessary to transmit the training signal for each burst transmission to compensate for variations in radio propagation characteristic. Therefore, the overhead becomes larger and thereby the throughput of the communications system is reduced. Contrarily, as the training bit length becomes shorter, the amount of transmission data is increased but the synchronization error is also increased. Similarly, in packet communications, the shorter the sync-bit length in a packet, the larger the symbol synchronization error.

SUMMARY OF THE INVENTION

An object of the present invention is to provide a demodulation method and apparatus which can achieve precise demodulation based on a preambleless signal.

Another object of the present invention is to provide a demodulation method and apparatus which can perform both synchronization and demodulation in a preambleless communications system.

According to the present invention, both synchronization and decoding are concurrently performed by decoding a received signal according to Viterbi decoding scheme and determining a time alignment function or a time mapping n(t) which indicates where the decoded sequence is located in a time period of the received signal.

According to an aspect of the present invention, in a method for demodulating a received preambleless signal which does not include a signal for synchronization but is encoded by a convolutional code, after converting the received preambleless signal to a received sequence in a sampling rate which is at least a predetermined symbol rate, a Viterbi decoder is synchronized with the received sequence to produce an output sequence while determining the alignment function n(t) so that a Viterbi-decoded sequence is closest to the received sequence.

More specifically, a received preambleless signal may be sampled and converted to a digital signal in a sampling rate which is M (M≧1) times the predetermined symbol rate. The digital signal is represented by x_t (t=1, 2, . . . , T), where t is a sampling index corresponding to a sampling time instant and T is the number of sampling points during a time

2

period of the received preambleless signal. On the other hand, an encoded signal f(w, n(t)) is generated from a data sequence w, where n(t)=1, 2, . . . , N_w (N_w is a length of transmitted sequence).

In this case, a cumulative error or distance D(w) may be represented by the following equation:

$$D(w) = \sum_{t=1}^{T} \|x_t - f(w, n(t))\|^2. \tag{1}$$

Therefore, an operation of the present invention is to obtain the data sequence w and the alignment function n(t) so that the cumulative distance D(w) is minimized. In other words, this is a minimization problem of the cumulative distance D(w). Therefore, the dynamic programming represented by the following equations (2)–(4) can be used to solve such a problem.

$$d_w(t, n, j) = \| f_t(n, j) - x_t \|^2 \tag{2}$$

$$g_w(t, n, j_n) = \tag{3}$$
$$\min \left\{ \begin{array}{l} d_w(t, n, j = 0) + g_w(t - M, n - 1, j_{n-1} = 0), \\ d_w(t, n, j = 1) + g_w(t - M, n - 1, j_{n-1} = 1) \end{array} \right\}$$

$$D(w) = \min\{g_w(M(N_w + 1), N_w + 1, Je)/M(N_w + 1), \tag{4}$$
$$\ldots, g_w(T, N_w + 1, Je)/T\}$$

In these equations, n is a Viterbi decoding step, j is a state (j=, 2, . . . , J) (J=2^{K-1}) and an encoded signal $f_t(n, j)$ is generated by a Viterbi decoder corresponding to a Viterbi decoding step n and a state j, where K is a constraint length. That is, the distance $d_w(t, n, j)$ is a distance between the received sequence x_t and the encoded signal $f_t(n, j)$. Further, j_{n-1}, indicates two possible branches from previous states at step n–1 to the state j_n at step n (therefore j_{n-1}=0 or 1). It should be noted that n=0 and n=N_w+1 are a provisional step for calculation. Assuming that the state j at n=0 is J_{sw}, the state j at n=N_w+1 is J_e, and further the distance d_w(t, n=0, j=J_s) and the distance d_w(t, n=N_w+1, ij=J_e) are both zero.

Therefore, the alignment time function n(t) is obtained by using a sampling time instant t_o corresponding to D(w) in the equation (4) as follows:

$$n(t) = \left\{ \begin{array}{ll} Nw + 1 & t_0 < t \\ \dfrac{1}{M}(t - t_o) + N_w + 1 & t_0 - M(Nw + 1) \le t \le t_0 \,. \\ 0 & t < t_0 - M(Nw + 1) \end{array} \right. \tag{5}$$

The synchronized decoded sequence can be obtained by backtracking states providing min. $\{g_w(t_o-pM, N_w+1-p, J_{NW}=0), g_w(t_o-pM, N_w+1-p, J_{NW}=1)\}$, where p=0, 1, 2, . . . Such a backtracking step is known in Viterbi decoding.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a block diagram showing the functional configuration of a demodulator using a Viterbi decoder according to an embodiment of the present invention;

FIG. 2 is a time chart showing an operation of the embodiment as shown in FIG. 1; and

FIG. 3 is a graph showing the selected time alignment function n(t) in the embodiment.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

Referring to FIG. 1, there is shown a digital demodulator including a synchronization controller (distance calculator,

minimum distance detector, state memory, and N(t) decision)and a Viterbi decoder according to an embodiment of the present invention, which produces a synchronized decoded sequence from a received preambleless signal S_{IN} which does not have a preamble such as a training signal or a sync word. However, the received preambleless signal S_{IN} includes at least a signal which is encoded by a convolutional code having a constraint length of K.

An input section of the digital demodulator is comprised of a band-pass filter **101**, an extractor **102**, an analog-to-digital converter (ADC) **103**, and an extraction period estimator **104**. The band-pass filter **101** is set to a predetermined bandwidth which is M times the symbol rate f_{symb}, where $M \geq 1$. The extraction period estimator **104** receives the received signal S_{IN} and compares the power level of the received signal S_{IN} with a predetermined level P_{TH} to control the extractor **102** according to the comparison result. When the received power level is not lower than the predetermined level P_{TH}, the extractor **102** is closed to transfer the received signal to the ADC **103**. When it is lower, the extractor **102** is opened and thereby the received signal is not supplied to the ADC **103**.

After the received signal S_{IN} is limited to the predetermined bandwidth by the band-pass filter **101** and is extracted by the extractor **102**, it is converted into a digital signal x_t ($t=1, 2, \ldots, T$) by the ADC **103** according to a sampling rate f_{samp} which is M times the symbol rate f_{symb}. Here, t is the index of a sampling instant and T is the number of sampling instants during al extracted period by the extractor **102**. The digital signal x_t is stored onto a buffer memory **105**.

Subsequently, the digital signal x_t is output to a distance calculator **106** where a distance d_w is calculated by using the following equation:

$$d_w(t,n,j) = \|f_t(n,j) - x_t\|^2 \qquad (6)$$

where n is a Viterbi decoding step received from a Viterbi decoder **107**, j is a state (j=1, 2, ..., J) ($J=2^{K-1}$), and $f_t(n, j)$ is an encoded signal generated by the Viterbi decoder **107** corresponding to a Viterbi decoding step n and a state j. That is, the distance $d_w(t, n, j)$ indicates an error between the received signal x_t and the generated signal $f_t(n, j)$.

The distance $d_w(t, n, j)$ is added to the output of a minimum distance detector **109** (selector) by an adder **108** and then the output of the adder **108** is stored onto a state memory **110** (accumulator). The minimum distance detector **109** (selector) detects one which is smaller from cumulative distances $\{d_w(t, n, j=0) + g_w(t-M, n-1, j_{n-1}=0)\}$ and $\{d_w(t, n, j=1) + g_w(t-M, n-1, j_{n-1}=1)\}$ which are received from the state memory **110** (accumulator), that is,

$$g_w(t, n, j_n) = \qquad (7)$$
$$\min \begin{cases} d_w(t, n, j = 0) + g_w(t - M, n - 1, j_{n-1} = 0), \\ d_w(t, n, j = 1) + g_w(t - M, n - 1, j_{n-1} = 1) \end{cases}$$

where j_{n-1} indicates two possible branches from previous states at step n−1 to the state j_n at step n, therefore $j_{n-1}=0$ or 1. And then the detected one $g_w(t, n, j_n)$ is output to the adder **108**.

The state memory **110** stores a step n at a sampling index t, a selected previous state j_{n-1}, and cumulative distances $\{d_w(t, n, j=0) + g_w(t-M, n-1, j_{n-1}=0)\}$ and $\{d_w(t, n, j=1) + g_w(t-M, n-1, j_{n-1}=1)\}$ from the adder **108**.

The above calculations (6) and (7) are performed for each step n (=0, 1, 2, ..., N_w+1) and for each state j (=1, 2, ..., J), where N_w is a length of transmitted sequence. It should

be noted that n=0 and n=N_w+1 are a provisional step for calculation and that the state j at n=0 is J_s, the state j at n=N_w+1 is J_e, and further the distance $d_w(t, n=0, j=J_s)$ and the distance $d_w(t, n=N_w+1, j=J_e)$ are both zero.

When the calculations (6) and (7) are completed for all steps n (=0, 1, 2, ..., N_w+1) and for all states j (=1, 2, ..., J), a resultant cumulative distance $g_w(M(N_w+1), N_w+1, J_e)$ is stored in the state memory **110** (accumulator). In this manner, the following resultant cumulative distances $g_w(M(N_w+1)+1, N_w+1, J_e), g_w(M(N_w+1)+2, N_w+1, J_e), \ldots, g_w(T, N_w-1, J_e)$ corresponding to sampling instants $M(N_w+1)+1, \ldots, T$, respectively, are sequentially obtained and stored in the state memory **110** (accumulator). The resultant cumulative distances $g_w(M(N_w+1), N_w+1, J_e), g_w(M(N_w+1)+1, N_w+1, J_e), \ldots, g_w(T, N_w+1, J_e)$ obtained are output to a mapping decision section **111**, which determines the time alignment function n(t) as will be described hereinafter.

The mapping decision section **111** (synchronizer) calculates $g_w(M(N_w+1), N_w+1, J_e)/M(N_w+1), g_w(M(N_w+1)+1, N_w+1, J_e)/(M(N_w+1)+1), \ldots, g_w(T, N_w+1, J_e)/T$ corresponding to the sampling instants $M(N_w+1), M(N_w+1)+1, \ldots, T$, respectively. And the mapping decision section **111** (synchronizer) selects a minimum one from them to determine a sampling instant t_o at which the minimum one is obtained. When the sampling instant t_o is determined, the mapping decision section **111** (synchronizer) determines the time alignment function n(t) by using the following equation:

$$n(t) = \begin{cases} Nw + 1 & t_0 < t \\ \dfrac{1}{M}(t - t_o) + N_w + 1 & t_0 - M(Nw + 1) \leq t \leq t_0 \\ 0 & t < t_0 - M(Nw + 1) \end{cases} \qquad (8)$$

Further, the mapping decision section **111** (synchronizer) outputs the time alignment function n(t) to the Viterbi decoder **107** which produces the synchronized decoded sequence by backtracking a selected survivor path corresponding min $\{g_w(t_o-pM, N_w+1-p, J_{NW}=0), g_w(t_o-pM, N_w+1-p, J_{NW}=1)\}$, where p=0, 1, 2, ... The Viterbi decoder **107** performs the well-known decoding process using a digital received signal which is obtained from the received signal S_{IN} by a band-pass filter **112** and an ADC **113**.

The distance calculator **106**, the adder **108**, the minimum distance detector (selector), the mapping decision section **111** (synchronizer) and the Viterbi decoder **107** may be formed with a program-controlled processor such as DSP.

More specifically, the details of an operation when M=2 will be described referring to FIG. 2. Needless to say, the higher the sampling rate of the ADC **103**, the higher the precision of bit synchronization.

As shown in FIG. 2, assuming that a received sequence $\{x_1, X_2, \ldots, X_T\}$ during an extracted period is stored in the buffer memory **105**. In this case, the equations (6) and (7) are calculated during a period **201** from the sampling instant t=1 to 2(N_w+1) to produce the resultant cumulative distance $g_w(2(N_w+1), N_w+1, J_e)$ which is stored in the state memory **110** (accumulator). Similarly, at the end of a period **202** from the sampling instant t=1 to 2(N_w+1)+1, the subsequent resultant cumulative distance $g_w(2(N_w+1)+1, N_w+1, J_e)$ is produced. In this way, the following resultant cumulative distances are produced, and finally, at the end of a period **203** from the sampling instant t=1 to T, the resultant cumulative distances $g_w(T, N_w+1, J_e)$. These resultant: cumulative distances $g_w(2(N_w+1), N_w+1, J_e), g_w(2(N_w+1)+1, N_w+1, J_e), \ldots, g_w(T, N_w+1, J_e)$ are used to determine the time alignment function n(t) by the mapping decision section **111** using the equation (8), as shown in FIG. 3.

sequence, the alignment function indicating where the Viterbi-decoded sequence is located in the received sequence, and synchronizes the Viterbi-decoded sequence depending on the time alignment function to produce the output sequence.

8. The demodulator according to claim 6, wherein the sync controller comprises:

a distance calculator producing a distance between the received sequence and each of all possible Viterbi-decoded sequences;

an accumulator cumulating the distance in sampling points of the received sequence over a time period of the received sequence to produce a plurality of cumulative distances;

a selector selecting a minimum cumulative distance from the cumulative distances to determine the time mapping; and

a synchronizer synchronizing the Viterbi-decoded sequence with the received sequence to produce the output sequence depending on the time mapping.

9. The demodulator according to claim 6, wherein the sync controller performs the following equation (2) and (3) over the time period of the received signal, and then performs the following equation (4):

$$d_w(t, n, j_n) = \| f_t(n, j) - x_t \|^2 \qquad (2)$$

$$g_w(t, n, j_n) = \qquad (3)$$

$$\min \left\{ \begin{array}{l} d_w(t, n, j = 0) + g_w(t - M, n - 1, j_{n-1} = 0), \\ d_w(t, n, j = 1) + g_w(t - M, n - 1, j_{n-1} = 1) \end{array} \right\}$$

$$D(w) = \min\{g_w(M(N_w + 1), N_w + 1, Je) / M(N_w + 1), \qquad (4)$$
$$\ldots, g_w(T, N_w + 1, Je) / T\}$$

where, n is a Viterbi decoding step, j is a state (j–1, 2, . . . , J) (J–2^{K-1}), and an encoded signal ft(n, j) is generated by the Viterbi decoder corresponding to a Viterbi decoding step n and a state j, where K is constraint length, j$_{n-1}$ indicates two possible branches from previous states at step n–1 to the state j$_n$ at step n, n=0 and n=N$_w$+1 are a provision step for calculation, and J$_e$ is a state j at n=N$_w$+1, and further the distance d$_w$(t, n=0, j=J$_s$) and the distance d$_w$(t, n=N$_w$+1, j=J$_e$) are both zero.

10. The demodulator according to claim 9, wherein the sync controller determines a sampling time index to corresponding to D(w) in the equation (4), and then performs the following equation (5)

$$n(t) = \left\{ \begin{array}{ll} Nw + 1 & t_o < t \\ \dfrac{1}{M}(t - t_o) + N_w + 1 & t_o - M(Nw + 1) \le t \le t_o \\ 0 & t < t_o - M(Nw + 1) \end{array} \right\} \qquad (5)$$

11. The demodulator according to claim 6, further comprising:

a band-pass filter passing a baseband signal having a bandwidth of the sampling rate; and

an input extractor extracting the received signal from the baseband signal passing through the band-pass filter when a signal level of the baseband signal is greater

than a predetermined level, the received signal being transferred to the converter.

12. The demodulator according to claim 8, wherein the distance calculator produces the distance between the received sequence and each of all possible Viterbi-decoded sequences which are generated using a Viterbi-decoding step.

13. A method for demodulating a received preambleless signal which does not include a signal for synchronization but comprises a signal encoded by a convolutional code to produce an output sequence, the method comprising the steps of:

a) converting the received preambleless signal to a received sequence at a sampling rate which is at least a predetermined symbol rate;

b) decoding the received preambleless signal, after band-pass filtering and analog to digital conversion, into a Viterbi-decoded sequence at the predetermined symbol rate; and

c) synchronizing the Viterbi-decoded sequence with the received sequence to produce the output sequence while determining a time mapping so that the Viterbi-decoded sequence is closest to the received sequence, said step of synchronizing comprising generating the output sequence w and the time mapping n(t) so as to minimize a cumulative distance D(w) represented by the following equation (1):

$$D(w) = \sum_{t=1}^{T} \| x_t - f(w, n(t)) \|^2 \qquad (1)$$

where t is a sampling index of the received sequence, T is the number of sampling points during a time period of the received signal, x$_t$ is the received sequence, f(w, n(t)) is an encoded signal generated from the output sequence w.

14. The method according to claim 13, wherein the step c) comprises:

determining a time alignment function so that the Viterbi-decoded sequence is closest to the received sequence, the alignment function indicating where the Viterbi-decoded sequence is located in the received sequence; and

synchronizing the Viterbi-decoded sequence depending on the time alignment function to produce the output sequence.

15. The method according to claim 13, wherein the step c) comprises:

producing a distance between the received sequence and each of all possible Viterbi-decoded sequences;

cumulating the distance in sampling points of the received sequence over a time period of the received sequence to produce a plurality of cumulative distances;

determining the time mapping by selecting a minimum cumulative distance from the cumulative distances; and

synchronizing the Viterbi-decoded sequence with the received sequence to produce the output sequence depending on the time mapping.

* * * * *